THE RELATION OF MONTHLY FIRE OCCURRENCE IN GEORGIA TO MEAN MONTHLY VALUES OF WEATHER ELEMENTS[1]

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ABSTRACT

The monthly number of forest fires in Georgia from 1951 to 1958 is compared with the monthly mean values of weather elements to determine the relationship of fire danger severity to one or more of these elements. Although variations in human behavior unrelated to weather contribute to fire occurrence, a parameter composed of two of these weather elements, the relative humidity at 1330 EST and the maximum temperature, is found to be highly significant. This parameter is then used to estimate frequency of severe fire conditions from 1918 to 1951 when complete fire records were not maintained.

1. INTRODUCTION

Weathermen and foresters recognize the fact that certain weather elements exert considerable influence on the occurrence and consequent spread of forest fires. An objective means of relating monthly or seasonal forest fire danger to specific weather conditions is of value to fire control administrators. The fire danger meter now in general use in Georgia does this very well. When a sufficiently long period of data from this meter become available to compare with fire records, evaluation of Georgia's fire prevention efforts will be possible by the means Keetch [1] used in the Northeast.

A sufficiently large portion of Georgia has been under State fire protection since 1951 so that fire records from State-protected lands are considered representative of fire conditions for the entire State. Continuity in fire danger station records, however, exists for only a short portion of this time. During this period, the danger meters were changed from type 5 to type 8, many stations were changed from the woods to the open type, a change in wind reduction tables was made, and there were the normal changes in locations and exposures.

If a parameter based on weather observations from regular Weather Bureau Offices could be found, it would be useful at least until a long period of continuous fire danger station observations become available. In addition such a parameter might provide a reliable means of predicting prolonged periods of severe fire danger based on previous experience since weather records are available for a much longer period of time than fire records. This analysis was, therefore, made to find such a parameter: one that had continuity of record, was readily obtainable, had a good correlation with actual fire hazard from a statistical point of view, and was related physically to the burning process.

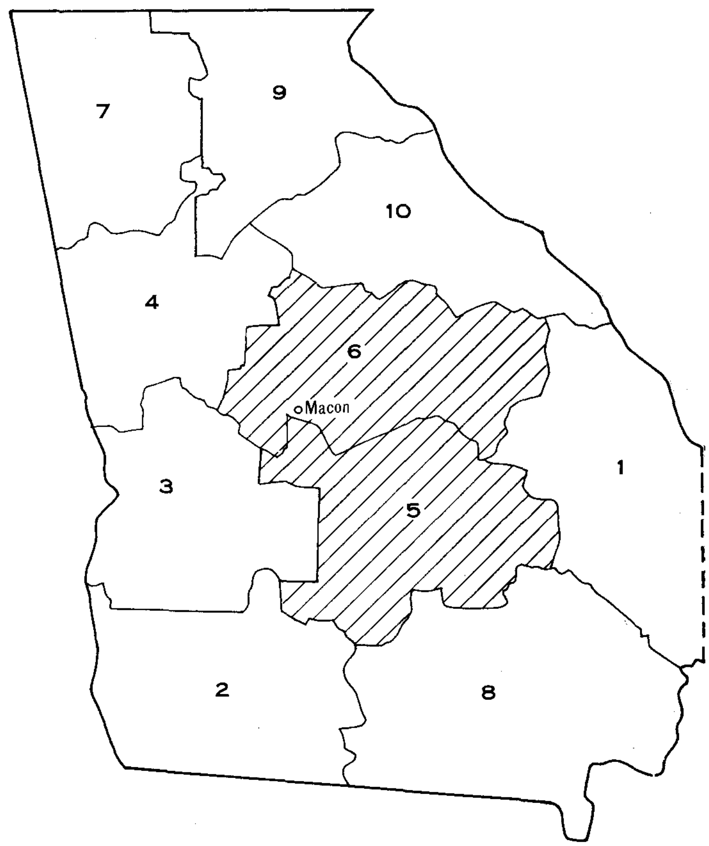

FIGURE 1.—Georgia Forestry Commission Districts. Note the location of Macon in relation to the 5th and 6th districts.

[1] A preliminary report of this study was presented at the Second National Conference on Agricultural Meteorology, 170th National Meeting of the American Meteorological Society, October 22–24, 1958, in New Haven, Conn.

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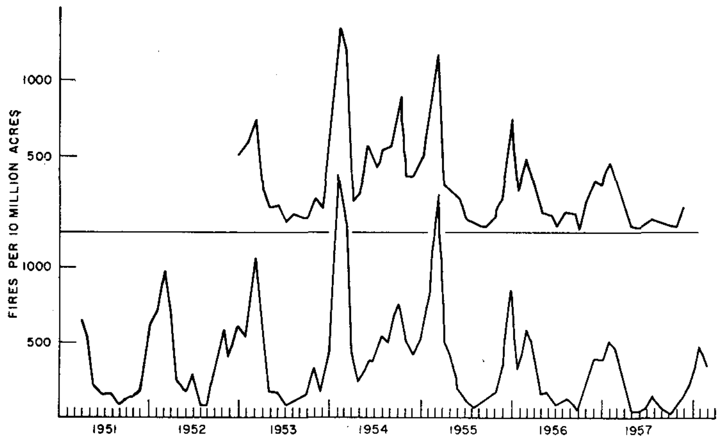

Figure 2.—Monthly fire occurrence per 10 million acres protected, for State of Georgia (lower) and 5th and 6th Districts (upper).

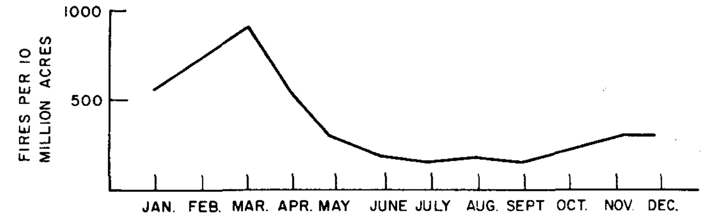

Figure 3.—Monthly average fire occurrence per 10 million acres protected, for State of Georgia during period April 1951 through March 1958.

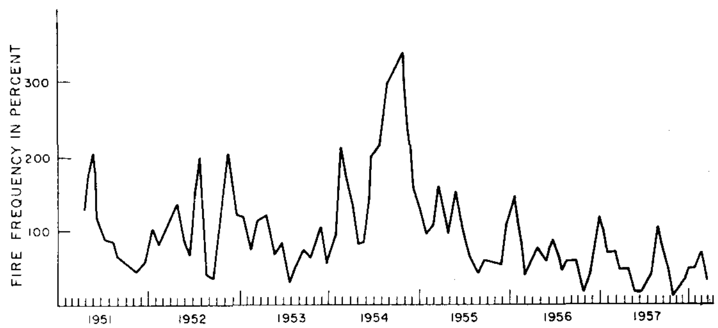

Figure 4—Monthly fire frequency for State of Georgia, expressed as a percent of the average for that month for the 7-year period 1951 to 1958.

2. PROCEDURE

Data used in this study were monthly fire records of the Georgia Forestry Commission and monthly weather data from the annual issues of *Local Climatological Data* for Macon, Ga., the Weather Bureau Office closest to the center of the State and, therefore, assumed to be most representative of the State as a whole.

Fire occurrence records appear to be reliable for the 7-year period April 1951 through March 1958, for that portion of Georgia under State fire protection. Prior to 1951, the area under protection was considered too small to give representative estimates of the fire occurrence for the State as a whole. Since April 1951, the area protected increased from 14 million to 22 million acres. In order to compare monthly fire occurrences, they were reduced to number of fires per 10 million acres protected. Similiar data were calculated for the 5th and 6th Georgia Forestry Commission Districts—the districts closest to Macon (fig. 1). Since a comparison of the variation in fire occurrence for the 5th and 6th districts with that for the entire State from 1953 through 1957 (fig. 2) shows only minor variations, the use of Macon weather data in State comparisons may be justified.

Total State fire occurrence on State-protected land shows a marked seasonal distribution (fig. 3) which may be related to such seasonal factors as greenness of vegetation, hours of daylight, amount of shade (primarily in hardwood stands), and seasonal changes in human activity. This seasonal effect was removed by expressing the total fire occurrence per 10 million acres each month as a percent of the average occurrence for that particular month during the 7 years of record (fig. 4). For convenience, this will be called fire frequency hereafter.

The monthly numerical values of maximum temperature, precipitation, 1330 EST relative humidity (the value closest to the minimum of those available), wind speed, percent of possible sunshine, and number of days with 0.01 inch or more of precipitation, as found in *Climatological Data* for Macon, were compared with numerical values of fire frequency. Other data available either were not considered to be related to the physical burning process or were essentially a duplication of the above data. For example, cloudiness would be related to sunshine and consequently was not included.

Seasonal effects were removed from the weather data by expressing the value of each weather element as the deviation from its average value for that month during the 7-year period of record. Hereafter, this will be referred to as deviation of maximum temperature, deviation of 1330 EST relative humidity, etc.

3. RESULTS

The deviation of 1330 EST relative humidity from the average was found to be most closely related to the fire frequency. Since relative humidity is related to fuel moisture, this relationship to fire frequency is what would be expected from physical reasoning. Because the scatter diagram (fig. 5) indicated a non-linear relationship, the regression equations for fire frequency vs. the logarithm, the inverse, and the square of the deviation from average relative humidity were computed. These variables were all significant at the 1 percent level. The inverse and the square were about equally significant, and both were considerably better than the logarithmic and the linear forms. When the equations were plotted on the scatter diagram the inverse curve appeared to give a better fit than the square in the area of high fire frequency. Thus the inverse curve was selected (fig. 5).

The residuals from this equation were then plotted against the deviations of each of the other weather elements. The relationship between the residual and maximum temperature was found to be significant at the 1 percent level. A multiple regression analysis was then computed for fire frequency using monthly deviations of maximum temperature and the inverse of the monthly deviations of relative humidity as the independent variables.

The residuals from this new equation were plotted against the remaining weather readings but no significant relationship could be found. Sunshine is closely related to maximum temperature and somewhat related to humidity, so these elements apparently already took care of any contribution sunshine could make. Average wind is so strongly influenced by high speeds in a few storms that the average value may be meaningless as a criterion of average weather conditions. Also, while wind is physically related to the spread of fire, its relationship to ignition is much less pronounced. Precipitation has only a brief effect upon the moisture content of some of the lighter fuels; even after a heavy rain in the morning, fires often start quite easily in the afternoon. Precipitation would have a noticeable effect, therefore, only if it occurred sufficiently near the time of daily minimum fuel moisture to keep the fuel moisture from reaching its usual low. These early afternoon rains are more than likely reflected in the 1330 EST relative humidity and the maximum temperature. Precipitation also varies so much over short distances that the Macon precipitation may not have been representative of average conditions over the State (both relative humidity and maximum temperature vary far less from place to place).

The final regression equation was

$$F=-31.74+\frac{2393.02}{H+20}+5.32T$$

where F is fire frequency in percent of the monthly average for the 7-year period, H is the deviation of 1330 EST relative humidity from the monthly average, and T is the deviation of maximum temperature from the monthly average. The multiple correlation coefficient was 0.83 which indicates that approximately 69 percent of the variation was accounted for by the two variables H and T. In view of the variation unaccounted for, the equation may have more value in dividing fire danger into broad categories such as severe, average, and low, than in determining specific fire danger values for each month. Arbitrarily, severe conditions were defined as those in which monthly fire frequency was greater than 150 percent of the 7-year monthly average, and low fire danger was defined as fire frequency less than 50 percent of the

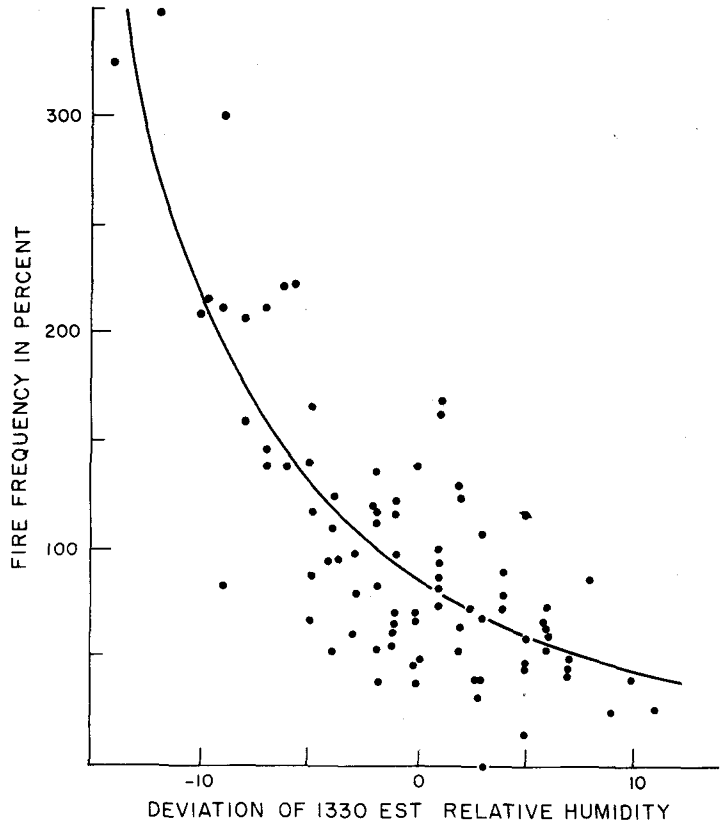

FIGURE 5.—Scatter diagram of monthly fire frequency vs. deviation from average monthly 1330 EST relative humidity. The curve shows the best-fitting inverse relation of fire frequency to deviation of relative humidity.

monthly 7-year average. Tables 1, 2, and 3 show the results of applying the equation and these definitions to the dependent data. The estimates from this equation for the three categories of fire frequency are 82 percent correct with a skill score [2] of 0.62. It is evident that the results are better on severe cases than on low cases, which was noted in selecting the inverse rather than the square of the humidity in forming the equation. If only two classes are used, severe and not severe (average and low combined), the forecasts are 95 percent correct with a skill score of 0.81. Severe fire conditions occurred in 13 months during the period; severe fire conditions would have been forecast for 10 of these 13 months. In one other month severe fire weather conditions would have been forecast, but they did not occur (table 4).

The equation has been tested on independent data from the period April 1958 through July 1959. Figure 6 shows both the scatter of these data and the results of dividing these data into the three classes. The skill score on the independent data was 0.46 for the three classes. In general, fire danger was low through most of

[2] Skill score is defined as $(R-E)/(N-E)$ where R is the number of correct forecasts, N is the total number, and E is the number expected to be correct from chance. See Brier and Allen [2].

TABLE 1.—*Contingency table for fire frequency forecasts by months (dependent data)*

Observed fire frequency	Forecast fire frequency			
	Severe	Average	Low	Total
Severe	10	3	0	13
Average	1	52	2	55
Low	0	9	7	16
Total	11	64	9	84

TABLE 2.—*Percent of time each forecast class occurred in each observed class (dependent data)*

Observed class	Forecast class		
	Severe	Average	Low
Severe	91	5	0
Average	9	81	22
Low	0	14	78
Total	100	100	100

TABLE 3.—*Percent of time each observed class occurred in each forecast class (dependent data)*

Observed class	Forecast class			
	Severe	Average	Low	Total
Severe	77	23	0	100
Average	2	95	3	100
Low	0	56	44	100

TABLE 4.—*Months when severe fire weather was forecast, observed, and both forecast and observed (dependent data except 1958)*

Year	Months											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Classification											
1951	—	—	—	—	B	—	—	—	—	—	—	—
1952	—	—	—	—	—	—	B	—	—	—	O	—
1954	—	B	F	—	—	B	B	B	B	B	O	—
1955	—	—	B	—	O	—	—	—	—	—	—	—
1956	B	—	—	—	—	—	—	—	—	—	—	—
1958	—	—	—	—	—	—	—	—	—	—	B	—

F=forecast but not observed.
O=observed but not forecast.
B=forecast and observed.

this period. It is felt that a higher skill score would be likely in a sample containing more severe months. The one month of severe fire weather conditions was correctly indicated by the equation.

4. DISCUSSION

A nomogram (fig. 7) was constructed from the equation and used to determine the months of severe fire weather in Georgia since 1918 (table 5). The fall of 1927 and almost all of 1954, known as bad fire periods, were indicated severe by the formula. Two or more consecutive severe fire months are rare, but as many as five

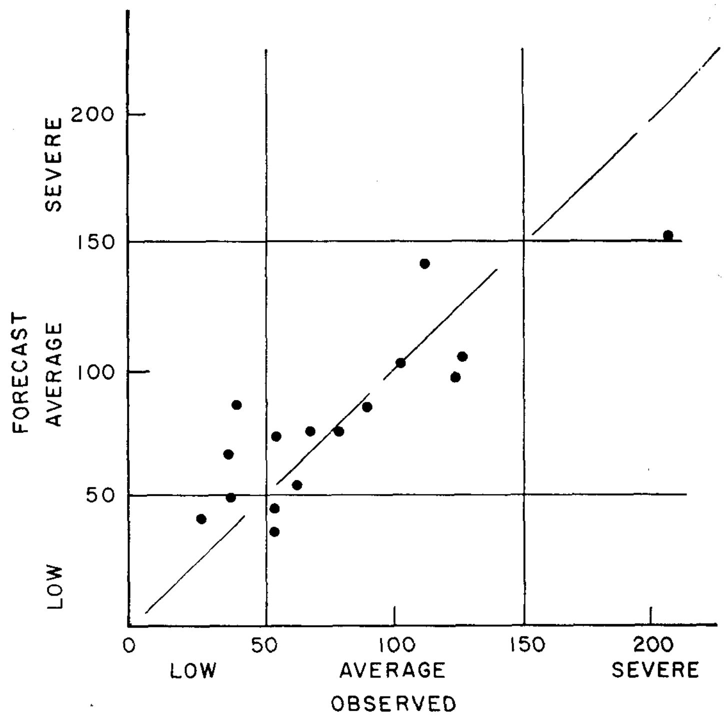

FIGURE 6.—Observed fire frequency vs. forecast fire frequency (independent data).

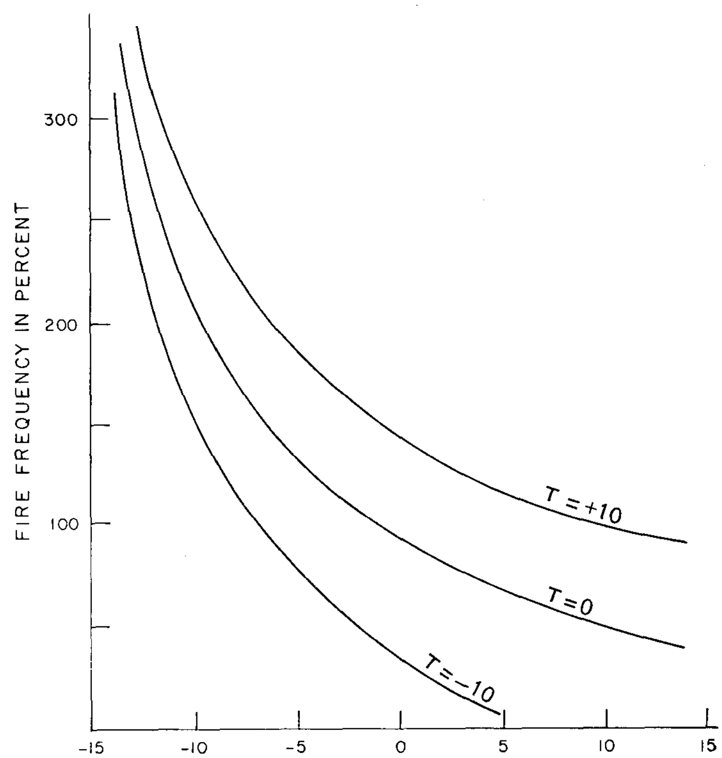

FIGURE 7.—Monthly fire frequency in percent of the average vs. deviation of 1330 EST relative humidity from the monthly average. Curves represent deviations of maximum temperatures of $-10°$, $0°$, and $+10°$ from the average.

TABLE 5.—*Months of severe fire weather in Georgia since 1918, as determined by monthly relative humidity and maximum temperature deviations*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Consecutive months	Years without severe periods
1918	—	—	x	—	—	—	—	—	—	—	—	—	1		
1919	—	—	—	—	—	—	—	—	x	—	—	—	1		1
1921	—	—	—	—	—	—	—	—	x	—	—	—	1		
1922	—	—	—	—	—	—	—	—	x	—	—	—	1		2
1925	—	—	x	—	—	—	—	—	x	—	—	—	2		1
1927	—	—	—	—	—	—	—	—	x	x	—	—	2	2	2
1930	—	x	—	—	—	—	—	—	—	—	—	—	1		
1931	—	—	—	—	—	x	—	—	—	—	—	—	1		
1932	—	—	x	—	—	—	—	—	—	—	—	—	1		3
1936	—	—	x	—	—	—	—	—	—	—	—	—	1		1
1938	—	—	—	—	—	—	—	—	—	x	—	—	1		2
1941	—	—	—	—	x	—	—	—	—	—	—	—	1		
1942	—	—	—	x	—	—	—	—	—	—	—	—	1		
1943	—	x	—	—	—	—	—	—	—	—	x	—	2		2
1946	—	x	—	—	—	—	—	—	—	—	—	x	2		
1947	—	x	—	—	—	—	—	—	—	—	—	—	1		3
1951	—	—	—	—	x	—	—	—	—	—	—	—	1		
1952	—	—	—	—	—	—	x	—	—	—	—	—	1		1
1954	—	x	x	—	—	x	x	x	x	x	—	—	7	2 and 5	
1955	—	—	x	—	—	—	—	—	—	—	—	—	1		
1956	x	—	—	—	—	—	—	—	—	—	—	—	1		1
1958	—	—	—	—	—	—	—	—	—	—	x	—	1		
Total	1	5	6	1	2	2	2	1	6	3	2	1	32	9	19

x=severe fire weather.

consecutive severe months have occurred. Severe conditions have occurred in all seasons but are most frequent in late summer and early autumn, and again in late winter. Over half (22 out of 41) of the years had at least one severe month. The longest consecutive number of years free of severe conditions was 3.

The physical relationship of these variables to fire occurrence appears logical. Fuel moisture, of course, varies directly with relative humidity and determines to a considerable degree the ease with which a forest fire may start. Temperature, on the other hand, has an inverse effect on fuel moisture and at high temperatures the fuel is closer to its kindling point.

These preliminary checks indicate that relative humidity and temperature deviations apparently account for a considerable portion of the variation in fire occurrence in Georgia for the period for which actual data are available. The residual may be partially accounted for by the fact that Macon weather is not always representative of that for the State as a whole. A much larger portion, however, is probably due to non-weather factors. From Davis's [3] summary, it is seen that 97 percent of Georgia fires are man-caused, and many are of incendiary origin. Although weather may control how often man's carelessness results in fire, it does not control how often man is careless. Education, fuel reduction, new fire laws, and other fire prevention efforts are generally conceded to have reduced the number of fires during recent years, but it is difficult to estimate the exact amount of reduction without an objective measure of weather influence.

5. CONCLUSIONS

Conclusions from this study, of course, are tentative and based only on the period and area for which data were used. They should be checked with data from other areas of Georgia as well as from surrounding States. The tentative conclusions are:

1. Fire frequency in Georgia is more closely related to humidity and temperature than to other weather elements, such as wind, sunshine, amount of precipitation, and frequency of precipitation.

2. The regression equation obtained in this study is usable to obtain past occurrences of severe fire conditions.

3. The equation may be of value in removing the effect of weather from fire records to evaluate success in fire prevention, assuming, of course, that the variation not accounted for is largely due to non-weather causes.

4. If in the future, long-term forecasts of average maximum temperature and minimum humidity (similar to the Weather Bureau's present 30-day mean temperature and rainfall predictions) become available, the equation may be of value to forewarn of severe fire conditions.

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